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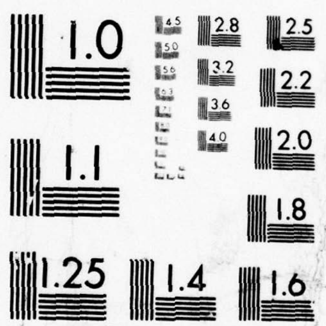

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FOREIGN TECHNOLOGY DIVISION

HOW FRICTION DISAPPEARED

by

M. Gurevich

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EDITED TRANSLATION

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Block	Italic	Transliteration	Block	Italic	Transliteration
А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*ye initially, after vowels, and after ъ, ь; e elsewhere.
When written as ё in Russian, transliterate as yё or ё.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

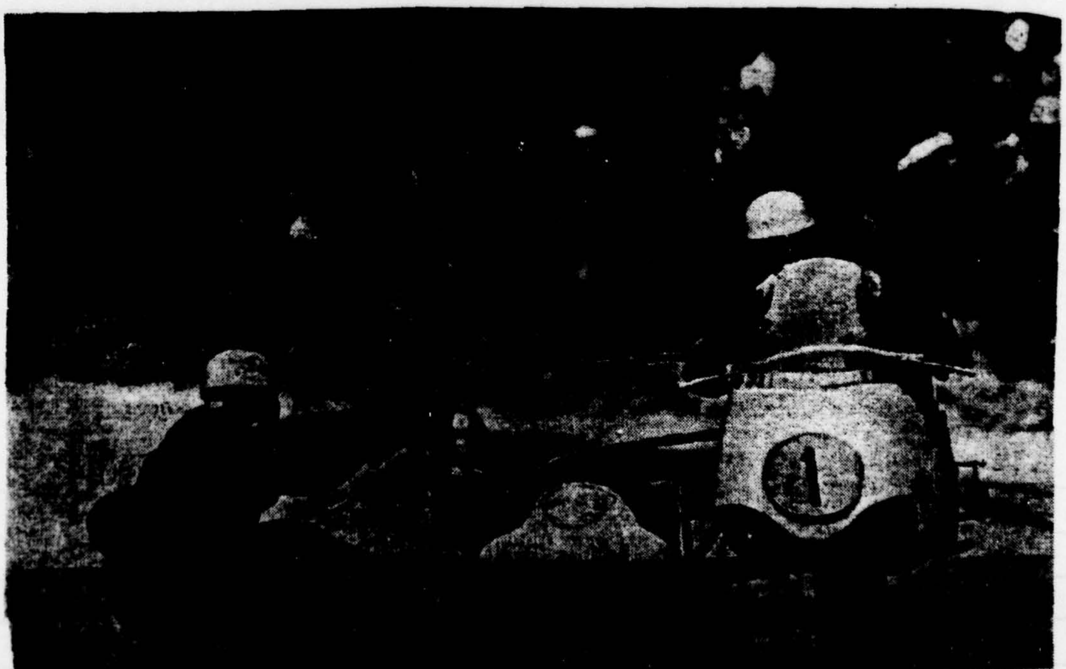
Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	$\sinh^{-1}$
cos	cos	ch	cosh	arc ch	$\cosh^{-1}$
tg	tan	th	tanh	arc th	$\tanh^{-1}$
ctg	cot	cth	coth	arc cth	$\coth^{-1}$
sec	sec	sch	sech	arc sch	sech^{-1}
cosec	csc	csch	csch	arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

PROBLEMS AND METHODS IN CONTEMPORARY SCIENCE

Soviet scientists Ye. A. Dukhovskoy, V. S. Onishchenko, A. N. Ponomarev, A. A. Silin, and V. L. Tal'rose 'discovered the phenomenon of super-low friction of solids... The use of the new phenomenon opens broad prospects for increasing the durability and reliability of machines and instruments which operate in an artificial and natural vacuum and in open outer space.

"Pravda," 25 October 1972



HOW FRICTION DISAPPEARED

M. Gurevich

> One of the authors of the discovery, Doctor of Chemical Sciences Ardal'on Nikolayevich Ponomarev, tells a correspondent of "Khimiya i zhizn'" about the new effect.

The Beginning

With each passing year more and more machines and mechanisms are operating under exotic conditions: in sea water, in a vacuum, in fluxes of ionizing radiation. By the way, of what exotics can there be talk if hundreds of apparatuses are already flying in outer space where there are both a deep vacuum and powerful radiations?

Approximately ten years ago we began to study the special features of friction under such conditions. It was possible to assume a prori that there are special features and they should have substantial influence on the operation of machines and mechanisms. Let us take the problem of lubrication. As a rule, it makes no sense to lubricate bearings which are operating in a vacuum: the lubricant heats up and evaporates. This means, it is necessary to select self-lubricating materials such as fluoroplastic and some inorganic compounds with additives of molybdenum disulfide.

It was also difficult to calculate that radiations would have no effect on the behavior of rubbing materials, especially plastic. Certain radiation-chemical transformations had to proceed in their surface layers which would certainly influence both the friction coefficient and wear resistance.

We constructed a simple experimental device whose operating principle can be explained, as they say, on the fingers. A steel ball is pressed with a certain force against a rotating disk of the material to be investigated. Two tensometers measure the pressure force of the ball against the disk and the friction and a recorder records the results of the measurements on a diagram. A compact radiation source focuses a beam of particles on the track over which the ball slides. The entire unit is located in a vacuum chamber where a rarefaction of 10^{-5}-10^{-6} mm Hg is maintained.

When the procedure had been debugged, we began the experiment: we began to irradiate various materials with electrons and ultraviolet rays. In some cases, the friction coefficient decreased by 10-20%, in other cases - it increased. And all the results found a reasonable explanation.

Let us say that on a polyethylene surface friction drops under the effect of radiation and on a fluoroplastic surface it increases. It is also understandable: polyethylene molecules become cross-linked in an irradiated layer and its structure becomes stronger while fluoroplastic, conversely, is subjected to destruction under these conditions.

In general our investigatory life proceeded without any surprises. We gave practical recommendations, published articles, and received authors' certificates for various new assemblies of laboratory units. It seemed as if it would have proceeded even farther if we had not set up one more experiment.

Attention: A Lamp is Burning!

In the summer of 1969, on one of the experimental units we replaced an electron gun with a helium source.

From the viewpoint of classical radiation chemistry, it would seem to make no difference what was used to bombard the surface

of the material under investigation: electrons, ions, or fast atoms. The entire thing is the power of the radiation which is absorbed by a unit of volume. But nevertheless, we wanted to see what would occur to friction under the effect of heavy particles.

A helium gun works as follows. Helium atoms flow into a glass flask in which a high-frequency discharge is burning. The positive helium ions which are formed in the discharge are accelerated in the electrical field and are directed to the surface of a rotating disk. (Here, there is a small detail which, perhaps, it would be useful to discuss. If a charged dielectric were to be positively irradiated with positive helium ions, nothing would occur. The ions would be repelled from the rapidly charged surface of the dielectric and would not give off their energy. Fortunately, the charge-exchange process occurs in the helium flux which is ejected from the gun: ions which have been accelerated by a field transfer their positive charge to the slow helium atoms and, as a result, become neutral particles: $*He^{+} + He \rightarrow He^{+} + *He$. In short, we bombarded the rubbing surfaces with helium atoms rather than with ions.)

The very first experiment with helium provided a truly amazing result: the curve of the friction coefficient which, in various experiments, sometimes rose somewhat higher than normal values and sometimes dropped slightly, unexpectedly dropped to the horizontal, zero axis of the diagram. In other words, within the limits of accuracy of our experiment we stopped perceiving friction. It dropped at least 100-fold.

This plunged us into such amazement that we began to look for errors in our well-checked methodology. Are there any unknown errors, unconsidered circumstances, was there any trivial experimental slip?

I repeat, I discussed the scheme for the experiment "on my fingers." But, as a matter of fact, it is extremely simple. It is

routine procedure which many used even before us. There were no doubts in the purity of the experiments. But nevertheless, we set up a control experiment which was required to provide an absolutely precise answer.

A steel plate with a tensometer is usually fastened on a rod which presses the ball to the disk. When the force of friction arises, the elastic plate bends and the sensor reacts to this bending. So, we brought a fine needle up to one end of the plate. The needle and the plate were connected with the source of current and a small bulb. If there is friction, the end of the plate departs from the needle, the circuit is opened, and the bulb does not burn. Simple, like a child's toy.

The control experiments followed one after the other. The helium gun had hardly begun to operate when the bulb invariably burned. Friction had actually disappeared!

The effect was established. It remained to explain it.

Repudiated Hypotheses

Before trying to explain any physical or chemical phenomenon, it is necessary to conduct at least approximate quantitative estimates. Let us do this.

It is clear that the effect of super-low friction is connected in some manner with the helium bombardment of the surface. Apparently, the short free path of heavy particles and, as a consequence, the circumstance that these particles manage to lose their energy in the finest surface film of the bombarded material which is only of several monolayers play a role here.

This energy can be estimated. The intensity of irradiation in our experiments was approximately 10^{-13} particles per second per 1 cm^2. Each of the helium atoms possessed an energy reserve

of about 2,000 electron-volts. If we take the thickness of the layer of material where the atoms completely give up their energy as 10^{-7} cm, it turns out that about 10 large calories are released in a cubic centimeter of plastic each second and in a cubic centimeter of plastic the radiation develops a gigantic power of 40 kW!

And immediately, an elementary explanation of the effect comes to mind: the instantaneous heating of the material, its melting, the sliding of the ball over the melted track.

The first self-evident hypotheses was rejected just as quickly as it was conceived. Yes, the specific energy release is tremendous. But the volume where this energy is released is painfully small: only several atomic layers. A simple calculation shows that there can be no macroscopic heating here; in an extreme case the surface heats up by only one degree.

But nevertheless, we undertook an experimental check. Simply speaking, we thrust a thermocouple into the ball. We could not register any temperature changes.

The following is a completely reasonable explanation. Irradiation can cause some radiation-chemical reactions in the material. Their products serve as a good liquid lubrication. This hypothesis also was quickly rejected. We took the best known lubricants, coated the rubbing surfaces with them, and began to measure the friction. The friction coefficient dropped several-fold but in no way to zero. By the way, these experiments were completely superfluous. For we obtained super-low friction not only on polyethelene and polypropylene, but also on inorganic materials - graphite and molybdenum disulfide, and it is impossible to squeeze any liquid products from them by any forces.

For the same reason, we rejected the hypotheses of a gas cushion. In principle, it would have been possible to assume that the hydrogen which is released during the destruction of the polymer

accumulates in the surface layer of the material and forms a gas cushion over which the ball rolls without any friction. But there cannot be any gas release with the irradiation of molybdenum disulfide and in the polyethylene and polypropylene so little gas is released that there cannot be any talk of a gas cushion.

True, there remained an illusory hope of explaining the effect by the formation of another cushion - electrical: as if the ball hangs above the disk in an electrical field. A calculation showed that this cannot be, either. But nevertheless, we permitted ourselves one more generally senseless but, in return, calming experiment: we placed a red-hot metal helix along side the disk so that the electrons which fly out from it neutralize the possible positive charge on the surface of the polyethylene. And as could be expected, this had no effect on the friction.

It turned out that it was incomparably more difficult to explain the effect than discover it.

Radiation Polishing

Such is the custom in science: when a new, let it be indisputable effect does not find clear theoretical substantiation, many stop believing in its existence. Recall the long-suffering magnetic or magnetized water. Concrete is already mixed in magnetic water, anti-boiling magnets are already being produced for boilers, but the skeptics do not believe in the effect and relate it to methodological errors, to experimental slips...

I cannot assert that we succeeded in creating a complete and final theoretical picture of the phenomenon. But now, much can already be explained.

Let us begin with generally known truths. Friction is inelastic losses in a material. At points of mutual contact of the macro-roughnesses which belong to rubbing surfaces, a shift of

the particles and an irreversible destruction of the material occurs and mechanical energy is converted to heat. If the surfaces are ideally polished and brought to the highest class of finish, to the gloss of a mirror, there will be no macro-roughnesses and friction will become less. But it will not disappear. Therefore, microscopic defects of the crystalline structure (dislocations, lattice vacancies, and so forth) - new sources of inelastic losses - remain on the rubbing surfaces. They cannot be eliminated by any mechanical or chemical polishing.

We believe that this can be attained only by intensive radiation processing. When the particles which are bombarding the surface give up their energy to the material, they excite its atoms. The atoms of the material exchange the acquired energy with each other (the energy migrates) until it reaches the micro-defects, nonuniformities, and dislocations. A defect in the material is an energy pit into which migrating electrons and holes and energy quanta of the excited atoms fall. So it turns out that the lion's share of the tremendous radiation energy is released in the places of non-uniformities. This means that here we have a density of energy which releases a power hundreds of times greater than the figure of 40 kW/cm^3 which amazed us. Further it is clear: under the influence of the radiation energy the defects are closed up, annealed, and disappear and the surface becomes truly ideal. There are no inelastic losses - and there is no friction!

This hypothesis explains in a completely satisfactory manner all our experimental results. It is clear why super-low friction does not set in immediately but after a certain grinding of the ball against the material: first it is necessary to smooth out the macro-relief and only then anneal the micro-defects. It is clear why immediately after the cessation of the helium processing the effect disappears and friction is restored: new nonuniformities arise immediately and new dislocations emerge on the surface from the thickness of the material. It is completely natural that radiation-resistant polystyrene may not even display sufficiently

expressed super-low friction: the radiation does not have enough energy to anneal strong micro-defects. Fluoroplastic does not provide the effect for the opposite reason: it is too unstable to radiation influences and new defects are formed more rapidly than the old ones are closed up.

Now we are trying to make the hypothesis of super low friction more rigid and precise. And for this, we are studying the electrical properties of surfaces and conducting their electron-microscope analysis. But it is still too early to speak of specific results here...

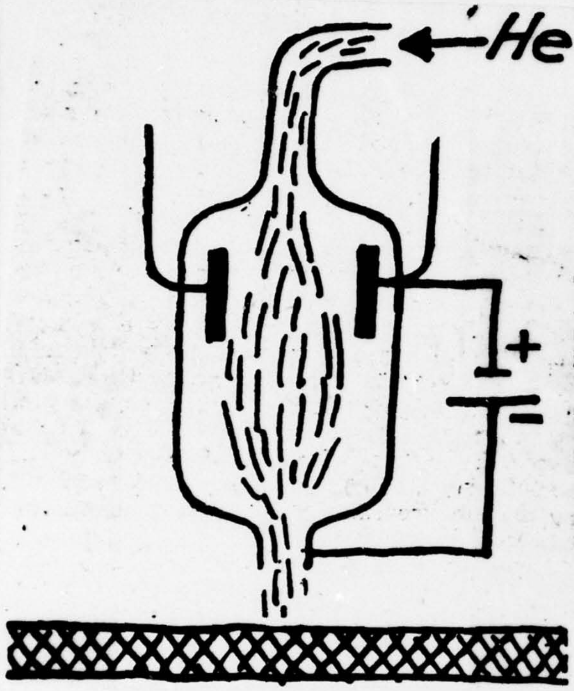
The Practical Value is Obvious

If the theoretical substantiation of super-low friction caused us serious difficulties, the practical use of the effect is obvious although many technical complexities are also expected here. It is hardly necessary to explain that a bearing without friction is an economy in energy which increases the service periods of machines many fold. And it is necessary to pay with rather small money - with infinitesimal energy for the acceleration of the helium beam.

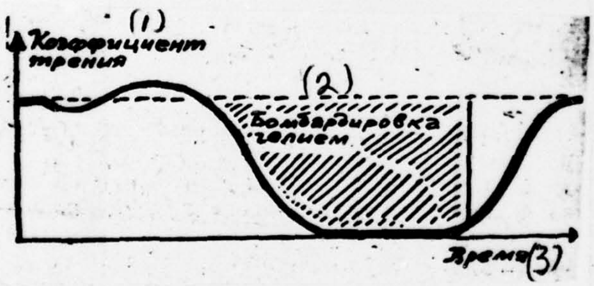
True, we are saying nothing about the vacuum. About the expenditure of energy to evacuate the air, about inconveniences, about design complications which vacuum technology brings to machine building. Well, vacuum bearings without friction are probably not necessary and useful for each machine. But they are a find for space vehicles. For vacuum pumps are not needed in outer space: any opening in the walls of the equipment is also a pump.

But it is a special conversation where we are talking about ground-based machines. In the end, our not so clever laboratory device is nothing other than a unit of some machine, a unit without friction. So that in principle, there is nothing improbable or

fantastic in bearings without friction for a regular ground-based machine such as an automobile or turbine, either. But this is already a matter not only for physicists and chemists but, to a large degree, for designers.

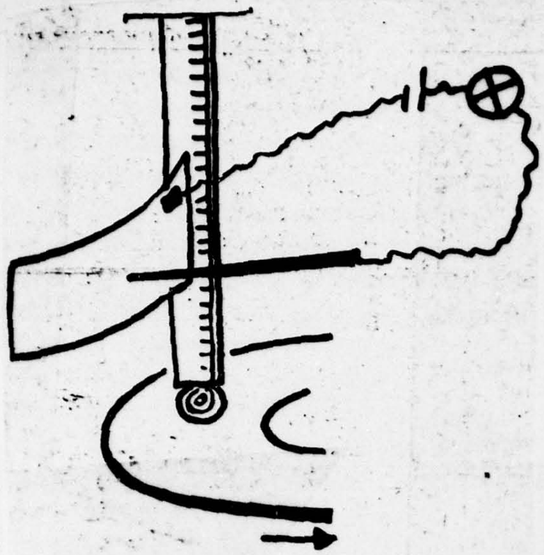


Helium gun. The helium flows into a glass cylinder where it is ionized in a high-frequency discharge. The electrical field accelerates the charged particles and ejects them through a capillary.



During the bombardment with helium, the friction coefficient drops to zero. After cessation of bombardment the effect disappears.

Key: (1) Friction coefficient; (2) Bombardment with helium; (3) Time.

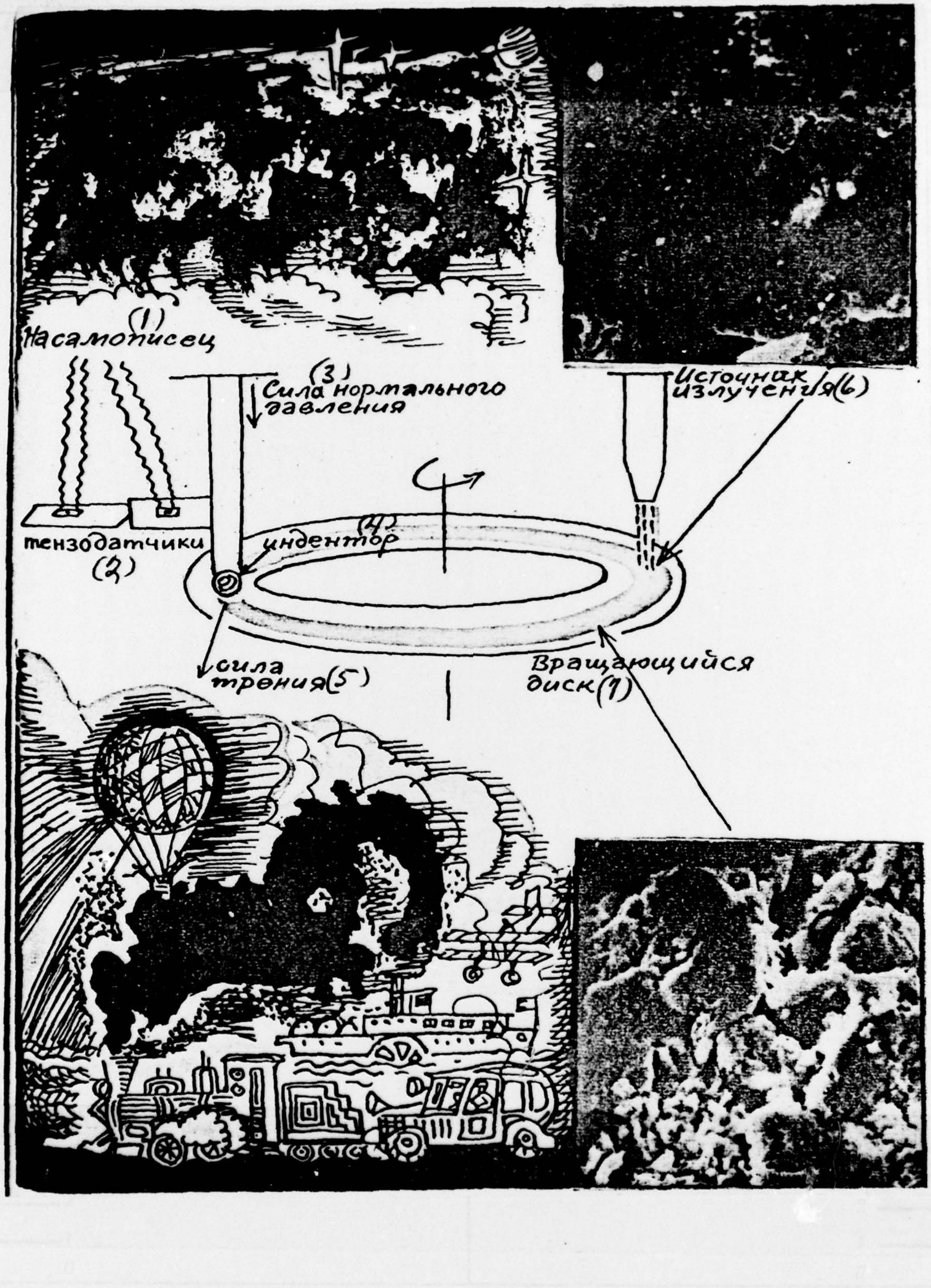


An experiment which unambiguously confirmed the existence of the effect of super-low friction. Under the action of the force of friction a thin steel plate should be deflected and open an electrical circuit: plate - battery - bulb - needle. If there is no friction the circuit is closed and the bulb burns.

[Picture on the following page.]

In the insert - the diagram of a unit for measuring friction coefficient. A steel ball - an indentor - is pressed against a rotating disk with a certain force. Tensometers measure the force of friction and the force of normal pressure. The device is located in a vacuum chamber where a rarefaction of 10^{-5}-10^{-6} mm Hg is maintained. The scientists who discovered the effect of super-low friction assumed that the tremendous energy which is released during the irradiation of the material by helium atoms smooths out the micro-defects on the surface and makes the surface ideal. To confirm this hypothesis, they photographed the surface of molybdenum disulfide prior to irradiation (lower photo) and after irradiation (upper photo). The surface of the irradiated material is considerably closer to the ideal than the surface prior to irradiation. The photos were taken using a scanning electron microscope with a magnification of 3000 times.

Key: (1) To recorder; (2) Tensometers; (3) Force of normal pressure; (4) Indentor; (5) Friction force; (6) Radiation source; (7) Rotating disk.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